The author is also professor of anaesthesia at Stanford University School of Medicine, Stanford, California.

Competing interests: The author is the secretary of the Anesthesia Patient Safety Foundation. He also licensed simulation technology to CAE-Link in 1992, for which he received a licence and royalties on the sale of patient simulators. He is also, periodically, a paid consultant to MedSim, the company that now owns the rights to the licensed simulation technology.


1 Leape L. Error in medicine. *JAMA* 1994;272:1851-7.
2 Cooper J, Newbower R, Long C, McPeek B. Preventable anesthesia mishaps: a study of human factors. *Anesthesiology* 1978;49:399-406.
3 Gaba D, Maxwell M, DeAnda A. Anesthetic mishaps: breaking the chain of accident evolution. *Anesthesiology* 1987;66:670-6.
4 Lunn J. Epidemiology in anaesthesia. London: Edward Arnold, 1986.
5 Derrington M, Smith G. A review of studies of anaesthetic risk, morbidity, and mortality. *Br J Anaesth* 1987;59:815-33.
6 Warden JC, Borton CL, Horan BF. Mortality associated with anaesthesia in New South Wales, 1984-1990. *Med J Aust* 1994;161:585-93.
7 Cooper JB, Newbower R, Kitz R. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. *Anesthesiology* 1984;60:34-42.
8 Cheney FW. The American Society of Anesthesiologists closed claims project: what have we learned, how has it affected practice, and how will it affect practice in the future? *Anesthesiology* 1999;91:552-6.
9 Runciman WB, Sellen A, Webb RK, Williamson JA, Currie M, Morgan C, et al. The Australian incident monitoring study. Errors, incidents and accidents in anaesthetic practice. *Anaesth Intensive Care* 1993;21:506-19.
10 Webb RK, Currie M, Morgan CA, Williamson JA, Mackay P, Russell WJ, et al. The Australian incident monitoring study: an analysis of 2000 incident reports. *Anaesth Intensive Care* 1993;21:520-8.
11 Bhasale AL, Miller GC, Reid SE, Britt HC. Analysing potential harm in Australian general practice: an incident-monitoring study. *Med J Aust* 1998;169(2):73-6.
12 Beckmann U, West LF, Groombridge GJ, Baldwin I, Hart GK, Clayton DG, et al. The Australian incident monitoring study in intensive care: AIMS-ICU. The development and evaluation of an incident reporting system in intensive care. *Anaesth Intensive Care* 1996;24:314-9.
13 Orkin FK, Cohen MM, Duncan PG. The quest for meaningful outcomes [editorial]. *Anesthesiology* 1993;78:417-22.
14 Petty C. The anesthesia machine. New York: Churchill Livingstone, 1987.
15 Arens J. Practice parameters: some new, others under development or revision. *ASA Newsletter* 1999;63:26-8.
16 Eichhorn JH, Cooper JB, Cullen DJ, Maier WR, Philip JH, Seeman RG. Standards for patient monitoring during anesthesia at Harvard Medical School. *JAMA* 1986;256:1017-20.
17 Drui A, Behm R, Martin W. Predesign investigation of the anesthesia operational environment. *Anesth Analg* 1973;52:584-91.
18 Weinger M, Herndon B, Gaba D. The effect of electronic record keeping and transesophageal echocardiography on task distribution, workload, and vigilance during cardiac anesthesia. *Anesthesiology* 1997;87:144-55.
19 Xiao Y, Milgram P, Doyle D. Incident evolution and task demands: an analysis and a field study of "going sour" incidents [abstract]. *Proceedings of the Human Factors Society's 36th Annual Meeting* 1992:1279-83.
20 Mackenzie CF, Craig GR, Parr MJ, Horst R. Video analysis of two emergency tracheal intubations identifies flawed decision-making. *Anesthesiology* 1994;81:763-71.
21 DeAnda A, Gaba D. The role of experience in the response to simulated critical incidents. *Anesth Analg* 1991;72:308-15.
22 Galletly D, Mushet N. Anaesthesia system errors. *Anaesth Intensive Care* 1991;19:66-73.
23 Gaba D. Human performance issues in anesthesia patient safety. *Problems in Anesthesia* 1991;5:329-50.
24 Eagle C, Davies J. Accident analysis of large-scale technological disasters applied to an anaesthetic complication. *Can J Anaesth* 1992;39:118-22.
25 Schwid HA. A flight simulator for general anesthesia training. *Comput Biomed Res* 1987;20(1):64-75.
26 Gaba D, DeAnda A. A comprehensive anesthesia simulation environment: re-creating the operating room for research and training. *Anesthesiology* 1988;69:387-94.
27 Good ML, Gravenstein JS. Anesthesia simulators and training devices. *Int Anesthesiol Clin* 1989;27:161-8.
28 Gaba D. The human work environment and anesthesia simulators. In: Miller R, ed. *Anesthesia*. 5th ed. New York: Churchill Livingstone, 1999.
29 Marsch S. Team oriented medical simulation. In: Henson L, Lee A, eds. *Simulators in anesthesiology education*. New York: Plenum Press, 1998.
30 Raemer D, Maviglia S, van Horne C, Stone P. Mock codes: using realistic simulation to teach team resuscitation management. 1998 Meeting of the Society for Technology in Anesthesia. Tucson, AZ
31 Kurrek M, Devitt J, Ichinose F, Bhatnagar G. Simulator team training: a concept beyond anesthesia. 1998 Meeting of the Society for Technology in Anesthesia. Tucson, AZ.
32 Raemer D, Barron D, Blum R, Frenna T, Sica G. Teaching crisis management in radiology using realistic simulation. 1998 Meeting of the Society for Technology in Anesthesia. Tucson, AZ.
33 Small SD, Wuerz RC, Simon R, Shapiro N, Conn A, Setnik G. Demonstration of high-fidelity simulation team training for emergency medicine. *Acad Emerg Med* 1999;6:312-23.
34 National Patient Safety Foundation. Prospectus of the NPSF: importance of leadership. Chicago, IL: NPSF, 1997. (www.ama-assn.org/med-sci/npsf/leader.htm; accessed 10 March 2000.)


# Using information technology to reduce rates of medication errors in hospitals

David W Bates

Division of General Medicine and Primary Care, Brigham and Women's Hospital, 75 Francis Street, Boston, MA 02115, USA

David W Bates *chief*

dbates@partners.org

*BMJ* 2000;320:788–91

Data continue to show that medication errors are frequent and that adverse drug events, or injuries due to drugs, occur more often than necessary.[1–4] In fact, the frequency and consequences of iatrogenic injuries seems to dwarf the frequency of other types of injuries that have received more public attention, such as aeroplane and automobile crashes.[2] A recent meta-analysis reported an overall incidence of 6.7% for serious adverse drug reactions (a term that excludes events associated with errors) in hospitals.[4] Between 28% and 56% of adverse drug events are preventable.[3 5–7]

Though the reasons this issue has received so little attention are complex, the reasons that medical injuries occur with some frequency are perhaps less so; medicine is more or less a cottage industry, with little standardisation and relatively few safeguards in comparison to, say, manufacturing. In fact, most of the systems in place in medicine were never formally designed, and this holds for the entire process of giving drugs.

Take, for example, the allergy detection process used in our hospital several years ago, which was similar to that used in most hospitals at the time. Physicians, medical students, and nurses all asked patients what their

## Summary points

Although information technologies are widely used in hospitals, relatively few data are available regarding their impact on the safety of the process of giving drugs

Exceptions are computerised physician order entry and computerised physician decision support, which have been found to improve drug safety

Other innovations, including using robots to fill prescriptions, bar coding, automated dispensing devices, and computerisation of the medication administration record, though less studied, should all eventually reduce error rates

The medication system of the future will include these and other technologies, all electronically linked

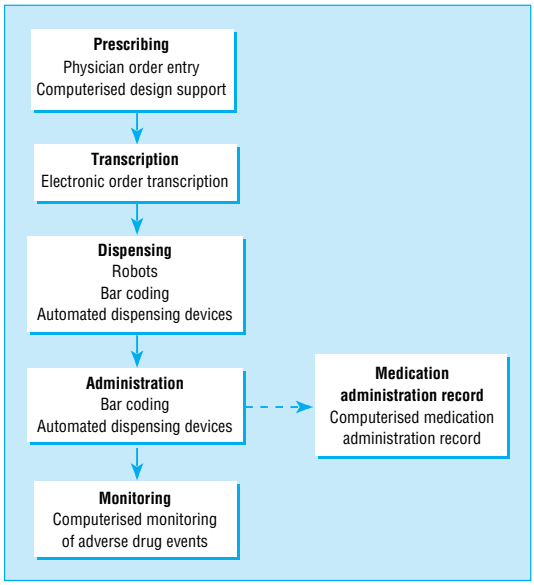


**Fig 1** Role of automation by stage in the medication process. Automation of some functions may affect more than one stage

allergies were. This information was recorded at several sites in the medical record, though there was no one central location. The information was also required to be written at the top of every order sheet, although in practice this was rarely done. The pharmacy recorded the information in its computerised database, but it found out about allergies only if the information was entered into the orders, and often it was not. Checking by physicians and pharmacy and nursing staff was all manual. This information was not retained between the inpatient and outpatient settings, or from admission to admission. Not surprisingly, about one in three orders for drugs to which a patient had a known allergy slipped through.[3] This system has been replaced by a system in which all allergies are noted in one place in the information system, drugs are mapped to "drug families" (for example, penicillin) so that checking of drugs within classes can be done, information is retained over time, and checking is performed by the information system, which does not fatigue.

## Using information technologies to prevent medication errors

Several interventions involving information systems have been shown to reduce medication errors considerably, and many others have promise but have not been sufficiently studied. Among these are computerised physician order entry, computerised physician decision support (which is often, though not necessarily, linked with order entry), robots for filling prescriptions, bar coding, automated dispensing devices, and computerisation of the medication administration record (fig 1).

It is essential to state at the outset, however, that information technologies are not a panacea, and that they may make some things better and others worse[8]; the net effect is thus not entirely predictable, and it is vital to study the impact of these technologies. They have their greatest impact in organising and making available information, in identifying links between pieces of information, and in doing boring repetitive tasks, including checks for problems. The best medication processes will thus not replace people but will harness the strengths of information technology and allow people to do the things best done by people, such as making complex decisions and communicating with each other.

### Computerised physician order entry

Computerised physician order entry (CPOE) is an application in which physicians write orders online. This system has probably had the largest impact of any automated intervention in reducing medication errors; the rate of serious errors fell 55% in one study[9] and the rate of all errors fell 83% in another.[10] Computerisation of ordering improves safety in several ways: firstly, all orders are structured, so that they must include a dose, route, and frequency; secondly, they are legible and the orderer can be identified in all instances; thirdly, information can be provided to the orderer during the process; and fourthly, all orders can be checked for a number of problems including allergies, drug interactions, overly high doses, drug-laboratory problems (giving a patient a drug when they have a known biochemical factor that predisposes them to risk), and whether the dose is appropriate for the patient's liver and kidney function (fig 2). A large decrease in the number of errors can be achieved by computerising the process even without providing much decision support; in one study even a simple system reduced medication errors by 64%.[10]

Computerised decision support is also valuable for reducing the frequency of adverse drug events, even when not linked to computerisation of the ordering process. In an elegant series of studies, the group from LDS Hospital in Salt Lake City, Utah, showed large reductions in adverse drug events due to antibiotics.[11] Also, a community hospital in Phoenix, Arizona, used a computerised alert system to target 37 drug-specific adverse reactions—for example, arrhythmia caused by digoxin—for which they looked for patients receiving digoxin who had hypokalaemia.[12] They detected opportunities to prevent injury at a rate of 64 per 1000 admissions; 44% of the true positive alerts had not been recognised by the physician.[12] This approach works partly by helping clinicians to associate key

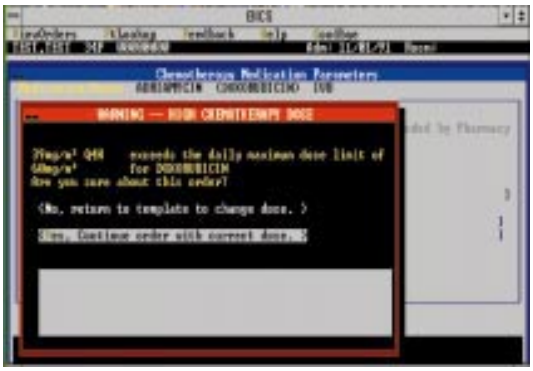

**Fig 2** Computerised checking of a chemotherapy dose. The computer calculates the body surface area, displays the calculation, and asks if it is correct. The dose is then checked against a table of doses, with daily and weekly limits. If a dose limit is exceeded the order is suspended until it can be reviewed and approved

pieces of data, which can be problematic given the overwhelming stream of data confronting them.

Though computerisation of ordering dramatically decreases the overall rate of medication errors, computerised decision support may be especially important for preventing errors that actually result in injury. In one study, computerised order entry with relatively limited decision support resulted in a larger decrease in near misses (84%) than in errors that actually resulted in injury (17%)[9]—but in a later evaluation, after more decision support had been added, the rate of errors resulting in injury fell from 2.9 to 1.1 per 1000 patient days.[10]

**Robots for filling prescriptions**

Automation may also reduce error rates in filling prescriptions. Robots have been used for this in some large hospitals for some time, and more recently in smaller hospitals, and they are increasingly being used in the outpatient setting. No published data are available, but in one unpublished study a robot decreased the dispensing error rate from 2.9% to 0.6% (PE Weaver and VJ Perini, American Society of Health System Pharmacists, 1998).

**Bar coding**

Although few data from health care are available, bar coding of drugs also seems useful for reducing error rates.[13] The major barrier to implementation has been that drug manufacturers have not been able to agree on a common approach; this should be legislated. Bar coding is widely used in many industries outside medicine; it results in error rates about a sixth of those due to keyboard entry and is less stressful to workers. Some hospitals in the United States have already successfully implemented bar coding—for example, at Concord Hospital in New Hampshire bar coding was associated with an 80% fall in medication administration errors (D DePiero, personal communication). Bar coding can rapidly ensure that the drug at hand is actually the intended one and can also be used to record who is giving and receiving it, as well as various time intervals.

**Automated dispensing devices**

Automated dispensing devices can be used to hold drugs at a location and dispense them only to a specific patient.[14] Such devices, especially if linked with bar coding and interfaced with hospital information systems, can decrease medication error rates substantially. Without these links the effect of these devices is unclear[14–16]; in one study such a system was actually associated with an increase in medication errors.[17]

**Automated medication administration record**

Another key part of the medication use process is the medication administration record, on which the clinicians who actually administer drugs record what has been given. Computerisation of this part of the process, especially if linked to computerised order entry, could reduce errors and allow detection of other types of errors relating to the quantities of drugs that are to be taken "as needed."

**Computerised adverse drug event detection**

To monitor how any process is performing, it is essential to be able to measure its outcomes. Traditional monitoring relies on self reporting, which radically underestimates adverse drug events, detecting only about 1 in 20.[18] However, computerised data can be used to detect signals (such as use of an antidote or a high concentration of a drug) that are associated with an adverse reaction.[19 20] A pharmacist can then evaluate the incident and determine whether it represents an adverse drug event, and these data can then be used for root cause analyses. In a head to head comparison with chart review and spontaneous reporting, a computerised monitor was found to detect 45% of events detected by any method, compared with 64% for chart review and only 4% for voluntary reporting.[20] The cost of the computerised monitoring was only 20% of that for chart review. This is the first practical way to monitor the medication process on an ongoing basis.

## Diffusion of these technologies

The tools that are now available should eventually be used in all hospitals; the overall approach should be analogous to that used in infection control, in which data about complications are used to continuously improve the system. Given the potential impact of these technologies, their diffusion has been surprisingly slow. One reason may be the lack of research showing how much of a difference the technologies make. Funding for such research has been relatively limited, and relatively little support has come from the developers of the technologies. Another, more important reason is lack of demand from the healthcare industry. Safety has not been a high priority in medicine, in part because the problem of safety is generally undervalued. One reason for this lack of appreciation is that medical accidents occur in ones and twos rather than in large groups; moreover, many of those involved are ill and elderly. Fortunately, public concern about the issue is substantial, and increasing, and the healthcare industry is beginning to take a more active interest.[21]

## The medication system of the future

In future, physicians will write orders online and get feedback about problems like allergies and decision support to help them choose the best treatment. The orders will be sent electronically to the pharmacy, where most will be filled by robots; complex orders will be filled by pharmacists. Pharmacists will be much more clinically oriented and will focus on promoting optimal prescribing and identifying and solving problems. Automated dispensing devices will be used by nurses to provide drugs to patients. All drugs, patients, and staff will be bar coded, making it possible to determine what drigs have been given to whom, by whom, and when.

## Conclusions

Several information technologies have been shown to improve the safety of drugs. Computerised physician order entry seems to be the most potent of these, and it can be expected to become even more useful as more data become computerised. The technology can be expected to diffuse rapidly as all major vendors are

developing such systems and many are pursuing internet based applications which would allow ordering and provide a common platform. Information technology should also improve safety in other parts of the process, including dispensing and administering, but the full benefits will not be achieved until all the components are electronically linked.

The net result of the above will be a much safer system, which will still require substantial human guidance. Moreover, the people using the system will have fewer menial tasks and a more rewarding role: physicians will discuss drug choices with patients and other providers rather than worrying about missing an allergy; pharmacists will deal with complex drug orders, counsel physicians about choices, and investigate problems that occur, rather than simply filling prescriptions; and nurses will talk with patients and monitor for adverse reactions, rather than just passing pills.

I thank Joshua Borus for help with preparation of the manuscript.

Competing interests: DB has received honoraria for speaking from the Eclipsys Corporation, which has licensed the rights to the Brigham and Women's Hospital Clinical Information System for possible commercial development, and from Automated Healthcare, which makes robots that dispense drugs. He is also a consultant and serves on the advisory board for McKesson MedManagement, a company that helps hospitals to prevent adverse drug events, and is on the clinical advisory board for Becton Dickinson.

1 Brennan TA, Leape LL, Laird N, Hebert L, Localio AR, Lawthers AG, et al. Incidence of adverse events and negligence in hospitalized patients: results from the Harvard Medical Practice Study. I. *N Engl J Med* 1991;324:370-6.
2 Leape LL, Brennan TA, Laird NM, Lawthers AG, Localio AR, Barnes BA, et al. The nature of adverse events in hospitalized patients: results from the Harvard Medical Practice Study. II. *N Engl J Med* 1991;324:377-84.
3 Bates DW, Cullen D, Laird N, Petersen LA, Small SD, Servi D, et al. Incidence of adverse drug events and potential adverse drug events: implications for prevention. *JAMA* 1995;274:29-34.
4 Lazarou J, Pomeranz BH, Corey PN. Incidence of adverse drug reactions in hospitalized patients: a meta-analysis of prospective studies. *JAMA* 1998;279:1200-5.
5 Classen DC, Pestotnik SL, Evans RS, Lloyd JF, Burke JP. Adverse drug events in hospitalized patients. Excess length of stay, extra costs, and attributable mortality. *JAMA* 1997;277:301-6.
6 Bates DW, Spell N, Cullen DJ, Burdick E, Laird N, Peterson LA, et al: The costs of adverse drug events in hospitalized patients. *JAMA* 1997;227: 307-11.
7 Bates DW, Leape LL, Petrycki S. Incidence and preventability of adverse drug events in hospitalized adults. *J Gen Intern Med* 1993;8:289-94.
8 Sheridan TB, Thompson JM. People versus computers in medicine. In: Bogner MS, ed. *Human error in medicine.* Hillsdale, NJ: Lawrence Erlbaum, 1994:141-59.
9 Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *JAMA* 1998;280:1311-6.
10 Bates DW, Teich J, Lee J, Seger D, Kuperman GJ, Boyle D, et al. The impact of computerized physician order entry on medication error prevention. *J Am Med Informatics Assoc* 1999;6:313-21.
11 Evans RS, Pestotnik SL, Classen DC, Clemmer TP, Weaver LK, Orme JF Jr, et al. A computer-assisted management program for antibiotics and other antiinfective agents. *N Engl J Med* 1998;338:232-8.
12 Raschke RA, Golihare B, Wunderlich TA, Guidry JR, Liebowitz AI, Peirce JC, et al. A computer alert system to prevent injury from adverse drug events. Development and evaluation in a community hospital. *JAMA* 1998;280:1317-20.
13 Chester MI, Zilz DA. Effects of bar coding on a pharmacy stock replenishment system. *Am J Hosp Pharm* 1989;46:1380-5.
14 Barker KN. Ensuring safety in the use of automated medication dispensing systems. *Am J Health Syst Pharm* 1995;52:2445-7.
15 Allan EL, Barker KN, Malloy MJ, Heller WM, Dispensing errors and counseling in community practice. *Am Pharm* 1995;35:25-33.
16 Borel JM, Rascati KL. Effect of an automated, nursing unit-based drug-dispensing device on medication errors. *Am J Health Syst Pharm* 1995;52:1875-9.
17 Barker KN, Pearson RE, Hepler CD, Smith WE, Pappas CA. Effect of an automated bedside dispensing machine on medication errors. *Am J Hosp Pharm* 1984;41:1352-8.
18 Cullen DJ, Bates DW, Small SD, Cooper JB, Nemeskal AR, Leape LL. The incident reporting system does not detect adverse drug events: a problem for quality improvement. *Jt Comm J Qual Improv* 1995;21:541-8.
19 Classen DC, Pestotnik SL, Evans RS, Burke JP. Computerized surveillance of adverse drug events in hospital patients. *JAMA* 1991;266:2847-51.
20 Jha AK, Kuperman GJ, Teich JM, Leape L, Shea B, Rittenberg E, et al. Identifying adverse drug events: development of a computer-based monitor and comparison to chart review and stimulated voluntary report. *J Am Med Inform Assoc* 1998;5:305-14.
21 *Massachusetts Hospital Association Bulletin* 1999 March 3.

# Gaps in the continuity of care and progress on patient safety

Richard I Cook, Marta Render, David D Woods

The patient safety movement includes a wide variety of approaches and views about how to characterise patient safety, study failure and success, and improve safety. Ultimately all these approaches make reference to the nature of technical work of practitioners at the "sharp end" in the complex, rapidly changing, intrinsically hazardous world of health care.[1 2] It is clear that a major activity of technical workers (physicians, nurses, technicians, pharmacists, and others) is coping with complexity and, in particular, coping with the gaps that complexity spawns.[3] Exploration of gaps and the way practitioners anticipate, detect, and bridge them is a fruitful means of pursuing robust improvements in patient safety.

## Summary points

- Complex systems involve many gaps between people, stages, and processes
- Analysis of accidents usually reveals the presence of many gaps, yet only rarely do gaps produce accidents
- Safety is increased by understanding and reinforcing practitioners' normal ability to bridge gaps
- This view contradicts the normal view that systems need to be isolated from the unreliable human element
- We know little about how practitioners identify and bridge new gaps that occur when systems change

## Gaps

The notion of gaps is simple. Gaps are discontinuities in care. They may appear as losses of information or momentum or interruptions in delivery of care. In practice gaps rarely lead to overt failure. Rather, most gaps are anticipated, identified, and bridged and their

VA Patient Safety Center of Inquiry (GAPS), University of Chicago, Chicago, IL 60637, USA
Richard I Cook *associate director*
VA Patient Safety Center of Inquiry (GAPS), Cincinnati, VAMC, Cincinnati, OH 45220, USA
Marta Render *director*

continued over

*BMJ* 2000;320:791–4